

## DROP QUANTITY CALIBRATION METHOD AND SYSTEM

### BACKGROUND

**[0001]** Inkjet printers have become increasingly sophisticated and can generate more complex images than before, including color photographic-quality images. Some inkjet printers have two or more pens, such as a high dye-load pen and a low dye-load pen, or multiple chambers within a single inkjet pen to handle a wide range of colors and hues. Differences in drop volume and/or drop weights between the pens, however, may cause noticeable color variations and/or hue shifts and generate images that do not accurately replicate desired colors.

### SUMMARY OF THE INVENTION

**[0002]** Accordingly, an embodiment of the invention is directed to a method of calibrating a device having a first fluid source that ejects a first drop quantity and a second fluid source that ejects a second drop quantity. An embodiment of the method comprises printing a pattern having a first portion and a second portion, wherein the first portion is printed by the first fluid source and the second portion is printed by the second fluid source; obtaining a relationship between the first drop quantity and the second drop quantity from the pattern; and adjusting data used to determine quantities of fluid to eject from the first fluid source or the second fluid source based on the relationship between the first drop quantity and the second drop quantity.

**[0003]** Another embodiment of the invention is directed to a calibration apparatus for a device having a first fluid source that ejects a first drop quantity to form a first region and a second fluid source to eject a second drop quantity to form a second region. The apparatus comprises an optical sensor to generate output from scanning the first portion and the second portion; and a processor arranged to receive the output, wherein the processor includes a configuration to determine a relationship between the first drop quantity and the second drop quantity using the output.

**[0004]** The embodiments described above are not intended to be exhaustive and other aspects of the invention will be apparent to those skilled in the art after reviewing the drawings and the detailed description below.

#### BRIEF DESCRIPTION OF THE DRAWINGS

**[0005]** Figure 1 illustrates a printing apparatus incorporating an embodiment of the invention;

**[0006]** Figure 2 is a block diagram illustrating a method according to an embodiment of the invention;

**[0007]** Figure 3 is a representative diagram of a test pattern generated according to an embodiment of the invention;

**[0008]** Figure 4 is a graph illustrating an optical scan of the test pattern of Figure 3 generated according to an embodiment of the invention;

**[0009]** Figure 5 is a graph illustrating an ideal relationship between the drop volumes and fill densities of matched pen pairs;

**[0010]** Figure 6 is a graph illustrating the effect of drop volume calibration on chroma; and

**[0011]** Figure 7 is a diagram of an embodiment of an optical sensor used to generate the test pattern scan such as that shown in Figure 4.

#### DETAILED DESCRIPTION OF THE EMBODIMENTS

**[0012]** Figure 1 illustrates a printer 101 that may incorporate an embodiment of the invention. For convenience in describing embodiments of the invention in the description below, all types of imaging systems are hereinafter referred to as "printers," all types, sizes, and compositions of print media are also referred to as "paper," and all fluid compositions are referred to as "ink;" no limitation on the scope of the invention is intended nor should any be implied. Moreover, imaging systems may also include, without limitation, copiers, fax machines, all-in-one imaging devices, and any other system that forms images by ejecting colored fluid onto a print medium. Further as used herein, the term "drop quantity" or "drop volume" are not intended to be limited to volumetric measurements or quantities, and are

intended to include other quantifiable quantity and/or spatial measurements or quantities, for example, without limitation, volume, mass, density, and/or weight. For instance, the term "drop quantity" can generally be used interchangeably with the terms "drop volume," "drop weight," or "drop density."

**[0013]** Housing 102 preferably encloses the electrical and mechanical operating mechanisms of the printer 101. Operation is administered by an electronic processor 103 (such as a microprocessor or application specific integrated circuit ("ASIC") controlled printed circuit board) connected appropriately to a computer (not shown). If desired, general purpose microprocessors or ASIC-executing firmware or software may be used to program and execute imaging, printing, print media handling, and/or control functions and logic operations. In an embodiment, the processor 103 functions may be performed by the computer, by electronics on-board the printer 101, or by interactions therebetween. The term "processor" as used herein encompasses these functions, whether performed by a computer, the printer 101, an intermediary device therebetween, or by a combined interaction of such elements.

**[0014]** In a preferred embodiment, ink-jet pens 115X may be individually mounted in a movable carriage 109. For example, without limitation, in a "full color" system, inks can be included for subtractive primary colors, i.e., cyan (X=C), yellow (X=Y), magenta (X=M) and true black (X=K). Further, if desired, an ink fixer (X=F) may also be included. However, the invention is not so limited and also contemplates the use of an integrated pen system, such as that in which pens 115X themselves may include one or more chambers (not shown). For instance, an integrated embodiment may include a plurality of pens (e.g., two pens) having a plurality of chambers (e.g., three) per pen. Reusable printhead systems are fluidically coupled by tubing 119 to replaceable or refillable ink reservoirs 117X (generally, in a full color system, inks preferably for the subtractive primary colors, cyan (X=C), yellow (X=Y), magenta (X=M) and true black (X=K) are provided; ink fixer (X=F) solutions are also sometimes provided). In a preferred embodiment, each pen 115X operates using an internal back pressure regulator for allowing transfer of ink

from a respective reservoir 117X while maintaining the appropriate back-pressure needed for the operation of each printhead of each pen. If desired, replaceable ink jet cartridges, such as those having a self-contained ink reservoir and back-pressure regulating mechanism, may be employed. Once a printed page is completed, the print medium is typically ejected onto an output tray 121.

**[0015]** Preferably, the embodiments of the invention operate within the printer 101 by comparing drop volumes of two or more pens and/or ink chambers 115X and using this comparison to reduce or remove color imbalances between the pens and/or chambers. In accordance with an embodiment of the invention, the relationship between the drop volumes may be determined without requiring a unique reference or calibration standard. Further, because primary and secondary inks may be printed on the same paper or media, in general, the effects of the paper or media will be relatively negligible. Two ink or fluid sources 115X, such as a high dye-load pen and a low dye-load pen, may be considered in a paired set, but embodiments of the invention may be used in any application that ejects ink from more than one pen (including those of different types) and/or chamber. In an embodiment, one pen is referred to as a "reference pen" and another pen is referred to as a "secondary pen". The terms "reference" and "secondary" correspond to the portions of a test pattern printed by each pen 115X and do not reflect the relative importance of the pens 115X during an actual printing operation.

**[0016]** Figure 2 is a block diagram illustrating a method according to an embodiment of the invention and Figure 3 illustrates one example of a possible test pattern generated in the method shown in Figure 2. Referring to Figures 2 and 3, the method 200 according to an embodiment of the invention involves printing a test pattern (block 202), which will later be scanned optically to detect drop differences between the two pens being compared. In the embodiment explained below, it is assumed that the relationship between, for instance, cyan and magenta in a low dye-load pen and, for example, yellow in a high dye-load pen is the intended focus. Embodiments of the

invention may be applied, however, to any color relationship between multiple pens without departing from the scope of the invention.

**[0017]** In this example, the ratio between the drop quantities of the two pens in a matched pen pair affects the "blue-yellow shift", or the degree of blue or yellow appearing in a printed image. For example, if the specified functional (e.g., nominal or optimum) drop quantity ratio between the high-dye load pen and the low dye-load pen is 5.0 nanograms/4.4 nanograms to obtain a correct or preferred balance of cyan and magenta to yellow, a ratio higher than the specified functional ratio may create an image that is too yellow, while a ratio lower than the specified functional ratio may create an image that is too blue. Ratio changes may occur if, for example, the drop quantity of either pen deviates from the specified functional drop quantity. If such variations are left uncorrected, the generated chroma values generated by the pen pair may vary from, for example, 0 to 20 for a given color, which may be an unacceptably high variance for some applications.

**[0018]** Figure 3 illustrates an example of a test pattern 300 that can be used to determine a drop volume relationship between the two pens to adjust or correct for "blue-yellow shift". The various portions of the test pattern 300 may be printed at selected increments along, for example, a width of a sheet of print media. Each increment can represent a "tile" 301. The increment size may be selected based on several designated factors, including, without limitation: anticipated extreme fill density ranges for pens being calibrated (e.g., a range between 14% and 41%); the field of view for the optical sensor (e.g., if the optical sensor has a viewing field of 1.25 mm, for example, the tile 301 may have a length of 2.5 mm, equivalent to two field views, to better prevent or reduce the influence of the preceding or following tiles 301 from influencing the results from the portion being examined by the sensor); and the resolution needed to determine a drop quantity difference. For example, in a preferred embodiment, each increment 301 may be represented as a grid, such as a 10x10 grid, with 100 possible ink deposition points.

**[0019]** The pattern 300 starts with a spit bar 302 generated by both pens to clear nozzles in the pens, stabilize pen temperatures, and stabilize drop

volumes before generating the remainder of the test pattern. After the spit bar 302, the pattern 300 includes a white space 304, a light absorbing portion 306, and a reference portion 308. The light absorbing portion 306 absorbs stray light and prevents or reduces the influence of unwanted signals on the results of optically scanning. The light absorbing portion 306 in a preferred embodiment is light black and printed in one tile.

**[0020]** Preferably, after the light absorbing portion 306 is printed, the reference portion 308 is printed by the reference pen at a known reference fill density. The reference fill density can have a value that is between the maximum and minimum fill density of the secondary pen. In an embodiment, the reference fill density is selected so that the calculated (e.g., average) response of the reference pen at the reference fill density will correspond to a point between the minimum and maximum fill densities of the secondary pen. For example, if the minimum fill density of a secondary pen is 14% and the maximum fill density is 41%, the reference fill density could lie between 14% and 41%. Of course, other minimum, maximum, and reference fill density values can be selected for alternate embodiments.

**[0021]** The color of the reference portion 308 is selected based on, for example, a spectral response of an optical sensor or scanner to be used for scanning the test pattern 300. In one example, the test pattern 300 will eventually be scanned with an optical sensor having a light source with a light output between 420 nm and 470 nm. To accommodate light sources in this range, a high dye-load reference pen may eject, for example, 19 parts magenta ink and 12 parts yellow ink to generate a reference portion 308 having a fill density of 19% magenta and 12% yellow. If the test pattern 300 will be scanned using a 420-470 nm light source, cyan ink is preferably not used to generate the reference portion 308 because cyan ink may not absorb the light from the light source as well and therefore may yield less useful information during the scanning process. Further, although a combination of two colors is used to generate the reference portion 308 in this embodiment, the reference portion 308 may be a single color or incorporate different color combinations depending on the specific characteristics of the light source. In

an embodiment, the reference portion 308 color is selected to better ensure that the spectral response generated by the reference portion 308 will remain sufficiently consistent even if there are small variations between the optical sensors generating the response for the same test pattern 300.

**[0022]** In a preferred embodiment, after the reference pen prints the reference portion 308, the secondary pen prints a test portion 310 containing one or more test tiles 311. In an embodiment, the test portion 310 has a smooth ink gradation representing increasing fill densities generated by the secondary pen. The secondary pen may generate the ink gradation over multiple test tiles 311, each test tile 311 having a fill density that is greater than the previous test tile 311. To do this, the secondary pen may fire ink at increasing fill densities along each increment 301 to form each test tile 311. For example, if each test tile 311 is represented by the 10x10 deposition point grid (such as noted above), the first test tile 311 may have 14 out of its 100 ink deposition points printed with ink (i.e., a fill density of 14%), while subsequent test tiles 311 may have fill densities increasing at a rate of 1% per test tile 311 along the test portion 310 up to 41% or some other selected or predetermined ending point.

**[0023]** Note that other starting and ending levels may also be used to print the test portion 310. In an embodiment, the starting and ending drop volume and fill density levels corresponding to a minimum and a maximum fill density for the secondary pen. The maximum fill density may correspond to, for example, a saturation threshold at which an increase in fill density would not change the optical sensor response. Further, the minimum fill density may be chosen to cover an expected or anticipated drop volume variation (e.g. based on manufacturing tolerances) between different pens. Regardless of the specific starting and ending values and the fill density increment between each test tile 311, the response of the secondary pen in generating the test tiles 311 will determine where the secondary pen drop volume corresponds with the reference pen drop volume to obtain the drop quantity ratio (e.g., 5.0 nanograms reference/4.4 nanograms secondary).

**[0024]** In an embodiment, the secondary pen is a low dye-load pen and the test tiles 211 are printed with black ink from the low dye-load pen. Black low dye-load ink often provides a preferred specified or an optimum signal response for certain light sources, such as the 420-470 nm light source noted in the example above. In short, the example described herein assumes that the 19% magenta/12% yellow ink reference combination represents the drop quantity of the reference pen and that the black ink represents the drop quantity of the secondary pen.

**[0025]** Referring back to the method shown in Figure 2, the test pattern 300 is optically scanned (block 204) with an optical sensor, such as the optical sensor shown in Figure 7. Preferably, an optical sensor records the signal levels of the test pattern 300 during the entire scan. In a preferred embodiment, the optical sensor first scans the reference portion 308 and measures a calculated (e.g., an average) signal response of the reference portion 308. As shown in Figure 4, the calculated signal response 400 for the reference portion 308 is relatively constant over its corresponding increment 301 because the color and the fill density of the reference portion 308 is also relatively constant. The signal response of each test tiles 311, however, varies as the fill density varies. As shown in the Figure, the signal response 402 for the test tiles 311 gradually decreases as the fill density of the test portion 310 increases along the test pattern 300.

**[0026]** Preferably, once the entire test pattern 300 has been scanned (block 204), the processor 103 compares the calculated (e.g., average) signal response of the reference portion 400 with the signal response of the test portion 402 (block 206) and finds an intersection point 404 between the calculated (e.g., average) reference portion signal response 400 with the test portion signal response 402 (block 208). In an embodiment, the starting and ending portions of the reference portion signal response are trimmed before calculating the calculated signal response 400 to better ensure that the calculated signal response 400 is calculated or determined from a more stable signal and not transient data generated as the optical sensor measures the start and end of the reference portion 400. For example, without limitation, the



invention may scan a subject pattern a plurality of times (e.g., four) and then average the associated signals at each position. In an embodiment, the average signal response of the scans can then be used in connection with a line fitting technique or other mathematical technique. However, it is important to note that the invention is not limited to a specified number of scans and any number of scans can be employed.

**[0027]** In an embodiment, a line 406 representing the calculated reference portion signal response 400 is extended until it crosses the test portion signal response 402 at the intersection point 404. The optical sensor processor then creates a fit line 408 based on a selected number of data points before and after the intersection point 404. The fit line 408 may also be generated using a variety of mathematical equations and/or approximation computations, however, a least squares fit method is preferred to better ensure that stray data points in the test portion signal response 402 do not give an undesirably skewed or an inaccurate representation of the actual test portion signal response 402. In an embodiment, for example, the sensor samples every fourth data point among 600 data points before and 600 data points after the intersection point 404. The fit line 408 is then generated from the sampled data points, and the intersection point 404 is re-evaluated and, if needed, re-adjusted to correspond with the point at which the calculated (e.g., average) reference portion signal response 406 intersects with the fit line 408.

**[0028]** In a preferred embodiment, once the intersection point 404 has been found, the processor 103 determines the position in the test portion 300 at which the intersection takes place to calculate a corresponding fill density for a secondary pen (block 210). Preferably, the optical sensor stores a corresponding position for each signal response. Further, the starting point of the test portion 310 and the increment size 301 of each test tile 311 is known (or can be determined). By correlating the intersection point 404 with a given position on the x-axis of the test pattern 300 generated by the optical sensor and determining the fill density of the test tile 311 in the test pattern 300 corresponding to that position, the fill density of a secondary pen at that position can be determined. In the particular example shown in Figure 4, the

intersection point 404 appears approximately at position 3600. By knowing the dimensions of each test tile, and knowing the starting location/position, and the fill % of the associated pattern, the fill % at the match position can be determined. In a preferred embodiment, the carriage system or pen transport system to which the sensor is mechanically and electrically attached, is driven by a servo system that utilizes an optical encoder to read position changes off of an encoder strip. The sensor and processor can also be used to find the edge of the test pattern. The foregoing specific values are for illustrative purposes only and are meant to show the technique for correlating the intersection point 404 with the corresponding fill density in the secondary pen; the example is not meant to be limiting in any manner.

**[0029]** The fill density of the secondary pen at the intersection point 404 is then converted into a relative drop quantity value that reflects a relationship between the secondary pen and the reference pen such as a drop volume difference between the secondary pen and the reference pen (block 212). In an embodiment, the drop volumes of the reference and secondary pens, in nanograms X 1000, are represented as follows:

$$\text{reference pen drop volume} = 75x + 2700 \quad (1)$$

$$\text{secondary pen drop volume} = -75x + 7100 \quad (2)$$

where  $x$  = the fill density. Note that the constant values in these equations are for illustrative purposes only and embodiments of the invention are not limited to the values described above. These equations indicate the drop volume that a properly or sufficiently matched reference pen and secondary pen could have to reduce the magnitude of or better prevent undesirable shifts in color, hue, and/or chroma. For instance, such drop volume equations can estimate a drop volume value that can be used to cause an associated color mapping system to adjust or scale the total number of drops that are deposited to better achieve "correct" or desired color rendering (e.g., to better match the color pens would nominally deliver).

**[0030]** Illustrative equations (1) and (2) above are linear equations, and therefore the estimated drop quantity for both the reference and secondary pens can be represented by straight lines, as shown in Figure 5. Note that values in Equations (1) and (2) are only one example of possible representations for the drop quantity. In practice, the equations can be determined empirically by evaluating many sets of pens and correlating to the fill % at the corresponding match position. Further, the invention is not limited to the use of linear equations and other equations may also represent the drop volumes and may be determined or developed empirically, for instance, to better reproduce preferred color output. In an embodiment, the coefficients in Equations (1) and (2) may be determined empirically by generating test patterns for multiple pens and/or printers, varying each pen over its full operating range, determining the relationships between the reference and secondary pens that reduce the blue-yellow shift to an acceptable level, and empirically determining best fit equations linking the matched fill densities and the drop volumes corresponding to these relationships.

**[0031]** Figure 5 illustrates the expected drop volumes of the reference pen and the secondary pen for a range of full densities. Referring to Figure 5 with respect to the specific example explained above, the secondary pen fill density at the intersection point 404 is predicted to be 28-29% if the pens are properly calibrated with respect to each other (e.g., if the ratio is 5.0 nanograms primary/4.4 nanograms secondary). If the ratio between the drop quantity of the reference pen and the secondary pen is higher than the specified or desired ratio, the intersection point 404 will occur at a secondary pen fill density that is greater than 28-29%. Conversely, if the ratio is less than the specified or desired ratio, the intersection point 404 will occur at a secondary pen fill density that is less than 28-29% in this example. Of course, if the reference fill density is a different value, the actual values for a secondary pen fill density corresponding to the specified ratio will be different, but the characteristics indicating re-calibration will still be the same. In an embodiment, an actual re-calibration process may involve calculating drop quantity values for primary and secondary pens to yield a correct drop

quantity difference that can be determined, such as from a test pattern. With the associated drop quantities for the pens, color maps or color rendering can be adjusted to shift the color output back towards nominal or preferred values.

**[0032]** Figure 6 is a graph illustrating one example of how the calibration method and system can affect the chroma of a printed image. In this example, a gray block is printed with the inventive calibration system (turned on and with the calibration system turned off) and the graph illustrates the chroma value of the gray block versus the fill % or fill density. Such a graph permits one to attempt to match the reference pen, which for the current illustrative example, has a chroma of about 6. Uncompensated, the chroma for such a reference may vary from 0 to 17, with 0 being yellow-shifted and 17 being blue-shifted. With calibration, the variation can be reduced to about 3 to 9, i.e., about a threefold improvement in color variation.

**[0033]** As noted above, the scanning process and various calculations can be conducted using an optical sensor that, in an embodiment, sends its data to a printer controller for processing. Figure 7 is a representative diagram of an optical sensor 600 that could be used in embodiments of the present invention. Various types of optical sensors 600 can be used in embodiments of the invention including, but not limited to, optical sensors having configurations similar to those generally described in commonly-assigned U.S. Patent No. 6,062,137 to Guo et al. U.S. Patent No. 6,036,298 to Walker, U.S. Patent No. 6,312,075 to Walker, or U.S. Patent No. 6,332,192 to Walker, the disclosures of which are incorporated herein by reference in their entirety.

**[0034]** In an embodiment, inkjet nozzles of the printheads are generally in-line with the sensor 600 in the x-axis by fixedly mounting the sensor 600 appropriately on the carriage 109 (Figure 1). Preferably, sensor 600 optically detects reflectivity values and provides electrical signals to the controller 103. As explained above, one or more light-emitting diodes ("LEDs") 602 can be mounted in the sensor 600 to illuminate at an angle to the plane of a printing zone in the printer 101. The LED 602 projects light onto the printed test pattern 300 and the light is then reflected to a photodetector 604. The LED 602 may include a die encapsulated in a transparent epoxy resin body that is

conformed to define an output lens as an integral dome lens that directs light from the die into rays that form an illuminating beam 606. Optical sensing and analog-to-digital ("A/D") signal processing techniques may be applied to interpret the data received by the photodetector 604 and generate graphic outputs, such as the one shown in Figure 4. The sensor 600 may be coupled to the processor 103 in the printer 101 or may have its own associated processor (not shown) to generate test pattern scan outputs for pen calibration.

**[0035]** Although some optical sensors in other applications may use multiple filters, an optical sensor 600 used in an embodiment of the invention may, if desired, include only one filter because embodiments of the invention measures spectral response of the test pattern 300 using a narrow band light source (e.g., 420-470 nm in the example described above). The embodiment would therefore use a filter covering the narrow band and would not need multiple filters to accommodate one or more light sources covering a broad band.

**[0036]** The illuminating beam 606 from the LED 602 is transmitted to the test pattern 300 and thereafter it is reflected off the test pattern 300 as a reflected light beam 610. In an embodiment, the area illuminated by the LED 602 is slightly larger than the viewing field of the photodetector 604 to better illuminate a selected viewing region by the LED 602. The reflected light beam 610 then enters a condenser lens 612, which focuses the reflected light beam 610 into the photodetector 604. In an embodiment, the condenser lens 612 has a focal length of approximately 5 mm (millimeters), but other focal lengths may also be selected in other optical sensor configurations and implementations having different packaging and placements of the sensor components. The photodetector 604 then generates an output signal to the printer controller 102 for analysis to generate the test pattern scan, such as the test pattern scan in Figure 4.

**[0037]** Although the description above focuses on detecting drop quantity variations between pens in a multiple-pen or multi-chamber printhead, embodiments of the invention may be used to detect variations between

multiple chambers in a single pen as well. Embodiments of the invention can be applied to, for example, a six-ink printer with one pen having high dye-load cyan, yellow and magenta ink and one pen having low dye-load cyan and magenta inks and a black ink. Embodiments of the invention can be used in any application that uses multiple ink sources to balance drop volume difference between two ink sources to give a correct hue of the color output.

**[0038]** While embodiments of the present invention have been particularly shown and described, it should be understood by those skilled in the art that various alternatives to the embodiments of the invention described herein may be employed without departing from the spirit and scope of the invention as defined in the following claims. It is intended that the following claims define the scope of the invention and that the method and apparatus within the scope of these claims and their equivalents be covered thereby. This description of embodiments of the invention should be understood to include all novel and non-obvious combinations of elements described herein, and claims may be presented in this or a later application to any novel and non-obvious combination of these elements. The foregoing embodiments are illustrative, and no single feature or element is essential to all possible combinations that may be claimed in this or a later application. Where the claims recite “a” or “a first” element of the equivalent thereof, such claims should be understood to include incorporation of one or more such elements, neither requiring nor excluding two or more such elements.